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UTILIZATION OF ADVANCED COMPOSITES IN
COMMERCIAL AIRCRAFT WING STRUCTURE:
EXECUTIVE SUMMARY (Douglas Aircraft Co.,
Inc.) 58 p HC A04/MP A01

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A Study on the Utilization of Advanced Composites in Commercial Aircraft Wing Structure

Executive Summary

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Contract NAS1-15004

July 1978



National Aeronautics and
Space Administration

Langley Research Center
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PREFACE

This summary report was prepared by the Douglas Aircraft Company, McDonnell Douglas Corporation, under NASA contract NAS1-15004, Study on Utilization of Advanced Composites in Commercial Aircraft Wing Structures. The study was conducted as part of the Composite Structures Element of the NASA Aircraft Energy Efficiency (ACEE) Program. The study program was monitored by Mr. Herman Bohon, ACEE Program Office, Langley Research Center. D. J. Watts was the Douglas Project Manager.

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SUMMARY

A study was conducted to define the technology and data needed to support the introduction of advanced composite materials in the wing structure of future production aircraft. In the course of the study, discussions were held with key personnel from airlines, the Federal Aviation Administration (FAA), and Douglas Aircraft Company Management. Their participation ensured that the study findings are representative for a broad segment of the commercial transport aircraft community.

The study accomplished the following:

- Definition of acceptance factors
- Identification of technology issues
- Evaluation of six candidate wing structures
- Evaluation of five program options
- Definition of a composite wing technology development plan
- Identification of full-scale tests
- Estimation of program costs for the total development plan
- Forecast of future utilization of composites in commercial transport aircraft
- Identification of critical technologies for timely program planning.

A comprehensive list of acceptance factors was formulated for the manufacturer, airlines, and FAA. Concurrence with the factors listed has been received from cognizant personnel from each of the three sectors.

A set of 24 issues was derived from the acceptance factors to form the basis for a technology assessment. Each issue was examined to determine which technological or economic problems must be resolved by a composite wing technology program. Recognition was given to probable contributions to the technology by other composite programs in government and industry so that they need not be repeated in a composite wing technology program.

Eight of the issues were classified as key issues:

- Durability
- Damage tolerance
- Crashworthiness
- Repair of major damage
- Lightning protection
- Molding methods
- Nondestructive inspection methods
- Large-scale tools.

These key issues are addressed in the development plan. Other issues will be addressed in the process of conducting a composite wing technology program, as defined herein.

Six candidate wing structures were evaluated for the baseline wing component. The DC-9-32 wing was selected on the basis of size, availability for commercial transport, availability of design, and the presence of design features that cover a realistic and comprehensive range of composite wing technology.

Five program options were formulated. Based on the technology assessment, it was determined that a common thread existed for all options:

- Design synthesis
- Development tests
- Manufacturing technology
- Operational technology
- Detail design.

The program options vary only in the size and quantity of full-scale hardware produced, in the amount of verification testing conducted, and in the scope of flight development and flight evaluation. Details of the program option which was selected for the composite wing technology program are defined in the development plan.

A conceptual composite wing box was designed which accounted for interface with adjoining structure and aircraft subsystems. A 28-percent weight saving was realized for this design compared to the existing metal wing design.

A development plan has been defined for the DC-9-32 composite wing box. Development activities are divided into six phases:

Phase I	Preliminary Design
Phase II	Detail Design
Phase III	Manufacturing
Phase IV	Full-Scale Tests
Phase V	Flight Development
Phase VI	Flight Evaluation.

Full-scale semispan composite wing box hardware will be fabricated rather than full-span hardware. This approach will eliminate the need for opposite-hand tools and reduce the quantity of hardware produced, which will lower costs.

The following full-scale tests are specified:

- Static ultimate
- Durability and damage tolerance
- Crashworthiness
- Repair of major damage
- Vibration.

The production facilities and equipment forecast for composite wing structures was made with the awareness that primary wing structure would be preceded by secondary and medium primary structure utilization throughout the airframe. A total floor space buildup to 55,742 square meters (600,000 square feet) dedicated to composite structures would be required to produce a production airplane with composite primary wing structure.

Total program costs for a composite wing development program is estimated at \$74.9 million (ROM) based on 1978 dollars. Of this total, 32 percent is allocated to the Phase I preliminary design and 45 percent to the Phase III manufacturing (includes tooling). The remaining 23 percent is approximately evenly divided among the other four phases.

A road map is presented for utilization of composite structures on future Douglas production commercial transport aircraft. This road map reveals

Company plans for a logical progression to a composite wing box on a short-haul transport planned for first production delivery in 1990.

The study concludes that it is highly improbable that a production commitment will be made until a comprehensive composite wing development program has produced data and technology sufficient to resolve the economic, programmatic, and technological risks identified by this study.

If the study objective of a composite wing box on a 1985-1990 production aircraft is to be realized, activity must be started in 1979 on the following key issues for which data are needed at the start of the preliminary design (Phase I) or which must be started early due to the time required to produce data and develop technology:

- Repair of major damage
- Impact damage (included in durability issue)
- Damage tolerance design studies and tests
- Innovative molding methods
- Tooling methods for large composite structures
- Lightning protection.

Activity on the remainder of the durability issue and other two key issues of crashworthiness and nondestructive inspection methods can be started later in Phase I since basic data for these technologies are available to support early preliminary design tasks.

INTRODUCTION

The overall wing study objectives are to study and plan the effort required by commercial transport aircraft manufacturers to accomplish the transition from current conventional materials and practices to extensive use of advanced composites in wings of aircraft that will enter service in the 1985-1990 time period.

Specific wing study objectives are to define the technology and data needed to support an aircraft manufacturer's commitment to utilize composite primary wing structure in future production aircraft and to develop plans for a composite wing technology program which will provide the needed technology and data.

Figure 1 presents a task flow diagram to achieve study objectives.

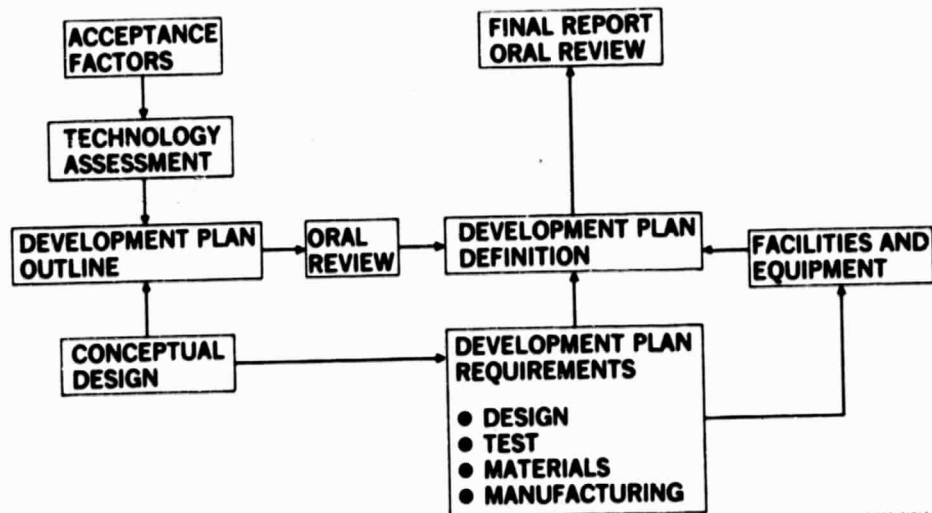


FIGURE 1. COMPOSITE WING STUDY FLOW DIAGRAM

ACCEPTANCE FACTORS

A manufacturer's decision to utilize composite wing box structure in commercial transport aircraft will be strongly influenced by the attitude of the airline operators and the FAA. Each considers many of the same factors, most notably structural integrity. Factors related to cost are of primary concern to the manufacturers and the airlines.

The acceptance factors listed in Table 1 form the basis for the technology assessment to identify those issues which must be resolved to gain airline acceptance, approval for airworthiness, and a manufacturer's commitment to production of composite wing box structure.

Airlines are becoming more interested in advanced composite materials because of their potential contribution to increased performance and reduced operating costs due to lower operating weights. What needs further validation to be accepted by the airlines is the potential for reduced maintenance costs when composite structures are used because of their excellent resistance to fatigue and environmental exposure.

The operational factors are of greatest concern to the airlines. The airlines know that the manufacturer and the FAA will emphasize the assurance of structural integrity, but feel that they must be vigilant to assure that once they have the aircraft, it can be maintained and inspected as readily and cheaply as an aircraft made with conventional structure. Off-runway incidents occur infrequently, but they do inflict major damage to wing primary structure. The composite wing structure must have restoration qualities equal to conventional wing structure, using repair facilities and equipment requiring the same out-of-service time as for repair of conventional wing structure.

FAA acceptance factors have been well defined. Guidelines have been drafted, and an FAA Advisory Circular entitled "Certification Guidelines for Civil Composite Aircraft Structures" (Reference 1) is being readied for publication. The guidelines were formulated by a joint FAA-NASA-DOD-Industry committee and the draft advisory circular received concurrence from the FAA and AIA in October 1977.

TABLE 1
ACCEPTANCE SUMMARY

	MANUFACTURER	AIRLINES	FAA
STRUCTURAL INTEGRITY FACTORS			
1. MATERIAL AND FABRICATION	X	X	X
2. STATIC STRENGTH	X	X	X
3. FATIGUE DAMAGE TOLERANCE	X	X	X
4. CRASHWORTHINESS	X	X	X
5. FLAMMABILITY	X	X	X
6. LIGHTNING PROTECTION	X	X	X
7. PROTECTION OF STRUCTURE	X	X	X
8. QUALITY CONTROL	X	X	X
9. REPAIR	X	X	X
10. FABRICATION METHODS	X	X	X
OPERATIONAL FACTORS			
11. RELIABILITY		X	
12. MAINTAINABILITY		X	
13. INSPECTABILITY		X	
14. REPAIRABILITY		X	
ECONOMIC FACTORS			
15. ACQUISITION COSTS		X	
16. LIFE-CYCLE COSTS		X	
17. WARRANTIES		X	
18. FACILITIES	X	X	
19. EQUIPMENT	X	X	
20. PRODUCTION COSTS	X	X	
PROGRAMMATIC RISK FACTORS			
21. DESIGN DATA	X		
22. PRODUCIBILITY DATA	X		
23. SCHEDULE DATA	X	X	
24. COST DATA	X	X	
25. STAFF EXPERIENCE	X	X	
26. AIRLINE ACCEPTANCE	X		
27. FAA ACCEPTANCE	X	X	

A management decision to utilize advanced composite structures will focus upon the level of risk involved, the value of the production improvement, the production costs, airline acceptance, and the aircraft manufacturer's ability to produce a certifiable composite wing structure.

TECHNOLOGY ASSESSMENT

The acceptance factors have been translated into a set of issues which need to be assessed as a prelude to defining the contents of a composite wing technology program. The issues can be categorized into four basic groups, as shown in Figure 2.

A total of 24 issues has been selected for the technology assessment based on the additional technology and data that are needed to promote acceptance of composite primary wing structure. It is assumed that all technology and data required to design, manufacture, and certify the earlier NASA ACEE secondary and medium primary structures will be available. For example, the secondary and medium primary structures utilize more thin-gauge panels, and the need for postbuckling strength allowables is greater than for strain-critical wing cover panels. Therefore, although a knowledge of postbuckling strength is desirable for minimum-weight wing structure, it is assumed the technology will be available and is not addressed in the wing technology assessment. Contributions from other government, industry, and in-house projects have also been anticipated to minimize the composite wing technology program costs.

Eight issues have been classified as key issues since their favorable resolution is essential to the timely production of composite wing structure, and specific technology development plans for their resolution must be included in the overall development program. The remaining 16 issues are also important, but it is deemed that these technologies will be adequately demonstrated in the process of conducting a composite wing technology program which contains provisions for certification of full-scale flight hardware by the manufacturer and FAA.

Five of the seven structural technology issues shown in Figure 3 are classified as key issues. Composite wing structure must be produced with the same level of structural integrity as for conventional aircraft wing structure and evidence of this must be provided as a condition of acceptance. Technical data must be generated during the design synthesis of a prototype development composite wing and proof of structural integrity must be demonstrated by full-scale testing.

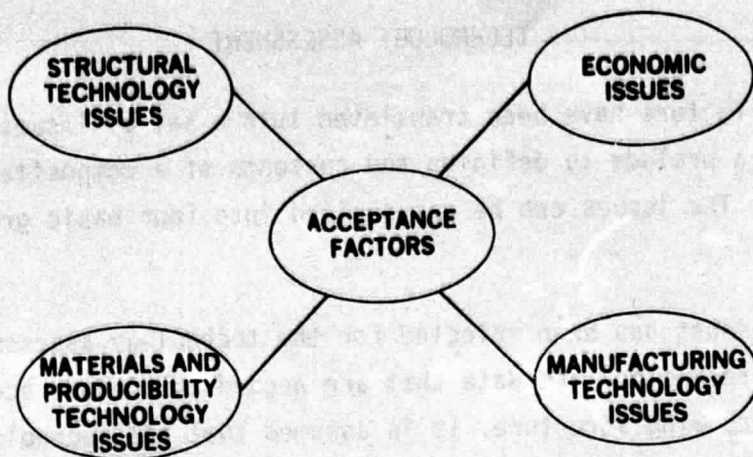
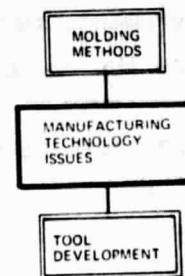
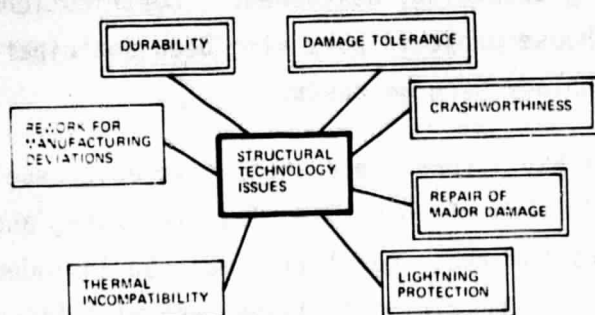


FIGURE 2. KEY ISSUE GROUPS



□ DENOTES KEY ISSUE

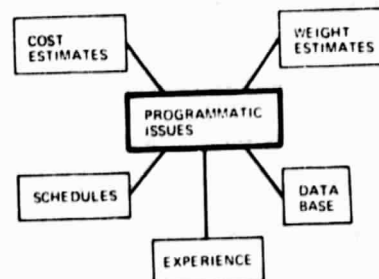
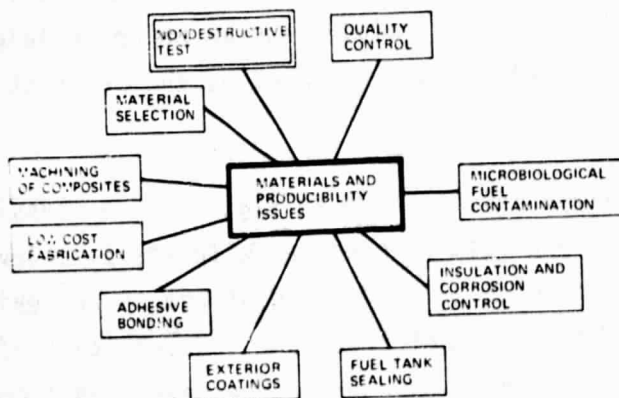


FIGURE 3. BASIS FOR TECHNOLOGY ASSESSMENT

The composite wing technology program will require provisions for acquiring durability test data, exercising the capability for designing durable structure, and demonstrating durable qualities by means of a full-scale fatigue test and an in-service flight evaluation.

The composite wing structure of a civil transport aircraft will be sufficiently different from these earlier programs to require further development of methodology correlated with experimental test data in order to develop an efficient wing design with adequate damage-tolerance capability. The structural integrity can only be proven by full-scale damage tolerance tests during a wing technology development program to demonstrate this capability to the satisfaction of the manufacturer and the airlines before embarking on a production program.

The FAA criterion for crashworthiness of the airframe is that occupants have every reasonable chance of escaping injury under realistic and survivable crash conditions. The known low ductility of composite materials makes the design of crashworthy wing structure more difficult and indicates a need to exercise and demonstrate this capability with graphite/epoxy wing structures.

Graphite/epoxy composite structures are much less conductive than the conventional aluminum aircraft structures, both electrically and thermally. Laboratory lightning test results have indicated that a lightning strike on an improperly designed graphite composite structure can seriously degrade its structural integrity (Reference 2). New design approaches to lightning protection are required for graphite composite structures with special emphasis on low-cost, lightweight, and ease-of-maintenance aspects of the protective hardware design.

A composite wing box for a commercial transport aircraft is built into the fuselage structure in a manner which makes wing replacement extremely costly, and replacement therefore cannot be considered as a viable alternative to repair, nor can a throwaway aircraft be considered. As stated earlier, one of the clearly defined conditions for airline acceptance is that the composite wing box structure can be repaired and returned to service. Repair costs and downtime should compare favorably with those of conventional wing structure.

Considerable testing will be required to provide repair technology data and

to prove to the airlines that proposed repair methods are viable and compare favorably with methods now used to repair conventional wing structure. Tests will be selected to supplement repair data being made available from other programs.

Eleven materials and producibility technology issues have been identified. Only the NDT method has been classed as a key issue. Complete inspection of composite wing structure requires the application of diverse NDT methods depending on the material, shape, configuration, thickness, and size of the test article, as well as types of flaws or damage to be detected. Methods are required for both production and service NDT evaluation. It is expected that cost-effective NDT methods and procedures must be established, inspection standards prepared, and acceptance quality levels determined that are applicable to composite wing structure. A knowledge of what NDT methods are to be employed and their capabilities is essential to the design synthesis of wing structure for which the initial and continued structural integrity must be ensured.

Manufacturing technology is composed of two key issues — molding methods and the development of large-scale tools. Manufacturing technology development is essential to the utilization of primary composite wings; it is needed early in the design cycle and should be one of the first issues resolved in a composite wing technology program. The composite wing manufacturing technology must be demonstrated by construction of full-scale wing structure and then proven by conducting full-scale tests in accordance with Reference 3.

Initial manufacturing technology available for composite commercial transport primary wing structure is derived from experience with other NASA ACEE composite structure programs as well as DOD-sponsored composite programs, notably the Grumman B-1 composite horizontal stabilizer and the AV-8 Harrier composite wing programs (References 4 and 5). These thin-wing components feature slab-skin and multiple-spar construction designed to military criteria. Commercial transport wings are much thicker, have higher aspect ratios, have at least several times the wing area of the AV-8, and are designed to FAR 25 criteria. Airline maintenance and longevity requirements will also influence the design. Considerable attention must be given to development of manufacturing technology for large composite wing structures in order to ensure cost-effective, on-schedule wing structures which satisfy the stringent FAA structural integrity requirements.

Molding methods which have been proven adequate for smaller structures may not be the most suitable for high-aspect-ratio cantilever wing structure which features much greater span, chord, and thickness dimensions. Load intensities are much greater, and cover skins and spar caps will require thicker laminates with complex ply patterns to satisfy bending and torsional stiffness requirements at minimum weight. Design concepts for panels and joints are expected to be different from smaller structures and will influence the selection of molding methods.

Composite molding tools for 50-foot parts have not been designed or tested to determine where problem areas might occur. Wing contours employ compound curvatures and twist along the wing axis. Dimensional control of the contour is essential for aerodynamic performance, and extraneous warpage of a wing skin during cure would be unacceptable. Conventional tooling experience is limited to relatively small parts where thermal effects cannot be adequately extrapolated to full-sized wing sections.

The programmatic issues shown in Figure 3 are not classified as key issues because they will be demonstrated in the course of constructing and testing flightworthy hardware. An airframe manufacturer will not commit to production of composite wings until a high degree of confidence exists that low-weight flightworthy structure can be produced on schedule for predictable costs. The data and experience needed can only be gained by the design, manufacture, and test of a flightworthy composite wing box which contains a range of design features representative of those to be encountered in a new commercial transport wing.

A typical schedule for a new production aircraft schedule is shown in Figure 4. The time from a firm Company commitment to the airlines to first delivery is approximately 38 months. However, as shown, a structurally sound completed wing main box must be ready to be joined to the fuselage only 19 months after the commitment is made. The full-scale verification tests come later. The consequences of schedule delays or unacceptable structural performance requiring redesign and test could endanger the total program.

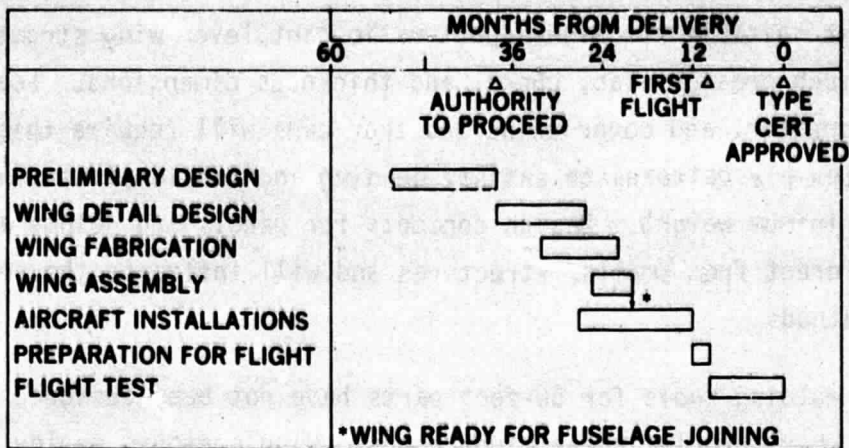


FIGURE 4. TYPICAL SCHEDULE DATA FOR A NEW PRODUCTION AIRPLANE

WING SELECTION

A baseline wing design is a prerequisite to the conceptual design of the composite wing box structure for the following reasons: (1) for weight saving, cost, schedule, and trade study comparison, (2) to define the scope of the development program, and (3) to determine facilities and equipment required.

Five aircraft wings were evaluated as prospective candidates for the composite wing technology program. Parameters considered included the following:

1. The vehicle should be a commercial transport aircraft wing with a range of design features to adequately demonstrate wing technology.
2. The wing should be a reasonable size to be cost-effective.
3. It should have the geometry, structural loads, environmental exposure, utilization rates, and FAA certification requirements typical for a future production aircraft.
4. Design data such as criteria, external loads, loft lines, and interface requirements must be readily available.
5. An aircraft must be available for a composite wing flight evaluation program. This implies certification by the FAA and subsequent revenue operation by a commercial airline.

These factors imply that the candidate wing options are limited to civil transport aircraft manufactured by the development plan contractor and currently in airline service, or at least far enough into development to ensure that design data are available and that an airplane will eventually be available for flight evaluation.

Accordingly, the five candidate wing options shown in Figure 5 were considered during the wing study:

1. The wing of the model C-15 STOL aircraft for the United States Air Force. Two prototype YC-15 aircraft have been built and flown. Since the study started, the Air Force has discontinued plans for C-15 production, and NASA now owns the two prototype aircraft. This airplane wing is a good size

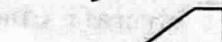
MODEL	MAX PAVEL LOAD		AREA		COMMERCIAL AIRPLANE	COMPLEXITY	1985-1990 PRODUCTION
	KN/M	(K/IN)	SQ M	(SQ FT)			
 C15	2100	(12)	43	(461)	NO	MAXIMUM (4 ENGINES)	POSSIBLE
 DC X-200	2100	(12)	47	(510)	YES	MAXIMUM (2 ENGINES)	YES
 DC-9	3150	(18)	19	(200)	YES	MINIMAL (TOTAL PROBLEM RANGE)	YES
 DC-10	4500	(26)	87	(941)	YES	MAXIMUM (2 ENGINES)	YES
 DC-8	700 (2450)	(4) (14)	17	(180)	YES	INADEQUATE (LOCAL PROBLEM AREA)	NO

FIGURE 5. WING OPTIONS

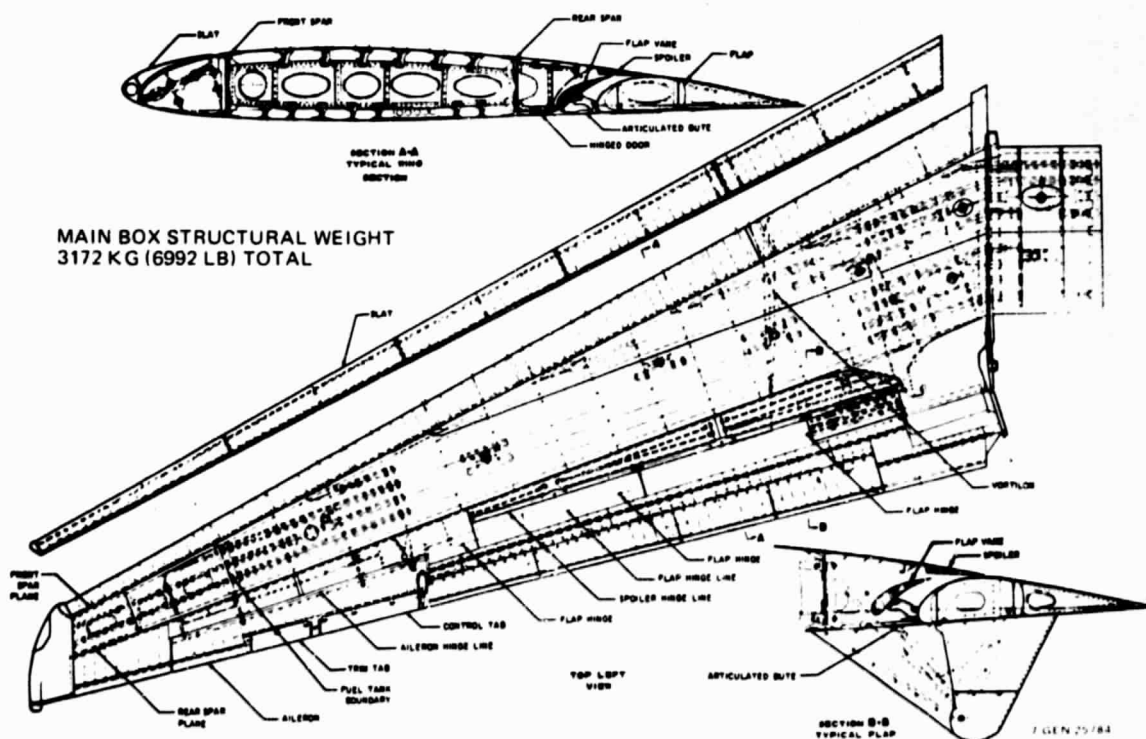
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for the development plan with adequate structural features for resolution of key issues. However, the airplane is not a civil transport and would not be suitable for in-service evaluation.

2. A DC-X-200 is currently in advanced design. Wing design data are available. The wing is a high-aspect-ratio supercritical wing which is probably representative of a 1985-1990 production aircraft and might be a good choice if a flight evaluation phase were not required in the development plan.
3. The DC-10 wing satisfies all requirements except that it is too large for cost and schedule factors. The design of the wing box does not lend itself to a spliced outer composite wing except outboard of the fuel tanks. This outboard section does not sufficiently represent inboard wing design features to address all the key issues (fuel tank wing-to-fuselage joining, main landing gear attach heavy structure, etc.).
4. Many DC-8 aircraft are still flying and design data are readily available. The full-span wing box is too large for an economical program, but the outboard wing has a design joint to the inboard wing. The size of the outboard DC-8 wing is ideal, but the objection mentioned for the DC-10 outboard wing applies equally to the DC-8 outboard wing: it is not representative enough to address all the key issues.

5. The DC-9 wing has the best attributes for the composite wing structural development plan. It is small enough so that the full wing can be used, data are available, many aircraft are in commercial service, and the wing design is representative.

Of the five wing options considered (Figure 5), the DC-9 aircraft easily out-ranked the other candidates on the basis of the parameters. There have been many different DC-9 models delivered to airlines. More than 320 model DC-9-32s have been delivered and the same wing is used on several other models, including freighter versions, the Air Force C-9A/VC-9C, and the Navy C-9B aircraft. The DC-9-32 airplane is still in production, and the vehicle will be available for flight evaluation in the mid-1980s. For these reasons, the DC-9-32 was selected for the conceptual design and development plan. The DC-9-32 wing structural arrangement is shown in Figure 6.



PROGRAM OPTIONS

Five program options have been conceived to provide a realistic basis for a contractual technology development effort that will resolve the issues which have been assessed for composite wing box structure. The options are shown in Figure 7. All options feature a DC-9-32 aircraft as the baseline configuration around which consistent, well-balanced, and comprehensive plans are formulated.

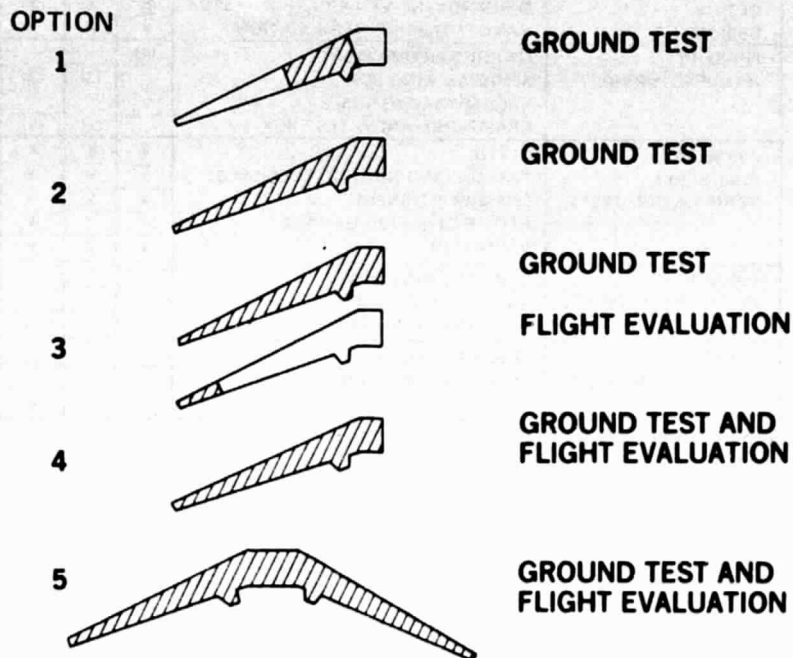


FIGURE 7. PROGRAM OPTIONS EVALUATED

Table 2 presents a summary of all five program options considered. It was considered essential to include provisions in all five options to (1) acquire technology and data, (2) gain design experience, (3) manufacture representative wing hardware, and (4) interface with the FAA to demonstrate the certification procedures for composite structures. The variation between options is therefore limited to the size and quantity of hardware to be manufactured, the amount of testing to be accomplished, and whether a flight evaluation program should be included. Figures 8 through 13 depict the details of the five program options. Figure 14 shows the approximate distribution of costs among the first five phases of Option 4.

TABLE 2
PROGRAM OPTION SUMMARY

PHASE	PROGRAM FEATURES	PROGRAM OPTION				
		1	2	3	4	5
PHASE I PRELIMINARY DESIGN	DESIGN SYNTHESIS	X	X	X	X	X
	LAYOUTS	X	X	X	X	X
	STRUCTURAL DEVELOPMENT TESTS	X	X	X	X	X
	MANUFACTURING TECHNOLOGY DEV	X	X	X	X	X
	REPAIR TECHNOLOGY	X	X	X	X	X
PHASE II DETAIL DESIGN	DETAIL DESIGN	X	X	X	X	X
	SUBCOMPONENT VERIFICATION TESTS	X	X	X	X	X
	MANUFACTURING VERIFICATION	X	X	X	X	X
PHASE III MANUFACTURING	MAJOR SUBCOMPONENT	(4)				
	SEMISPAN WING BOX		(3)	(3)	(3)	(1)
	FULL SPAN WING BOX					(2)
	CRASHWORTHINESS TEST BOX		(1)	(1)	(1)	(1)
PHASE IV FULL SCALE VERIFICATION TESTS	STATIC	X	X	X	X	X
	FATIGUE AND DAMAGE TOLERANCE	X	X	X	X	X
	CRASHWORTHINESS	X	X	X	X	X
	REPAIR OF MAJOR DAMAGE	X	X	X	X	X
	VIBRATION	X	X	X	X	X
PHASE V FLIGHT DEVELOPMENT	SEMISPAN WING BOX				(1)	
	FULL SPAN WING BOX					(1)
	OUTBOARD WING BOX			(1)		
PHASE VI SERVICE EVALUATION	SEMISPAN WING BOX				X	
	FULL SPAN WING BOX					X
	OUTBOARD WING BOX			X		

X INDICATES OPTION CONTAINS PROVISIONS FOR THE NOTED FEATURE
() INDICATES NUMBER OF UNITS TO BE MANUFACTURED

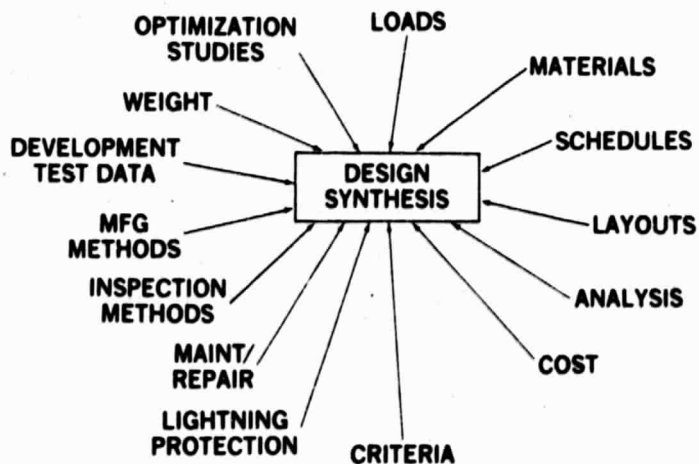


FIGURE 8. PRELIMINARY DESIGN – ALL OPTIONS

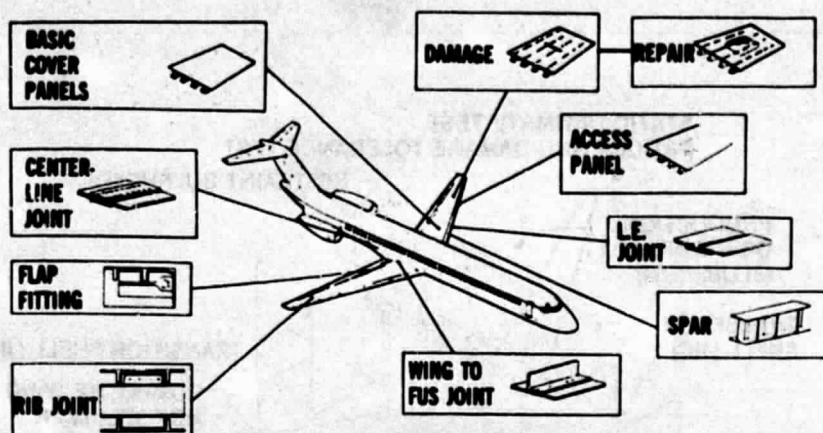


FIG 9-25/64

FIGURE 9. STRUCTURAL DEVELOPMENT TESTING – ALL OPTIONS

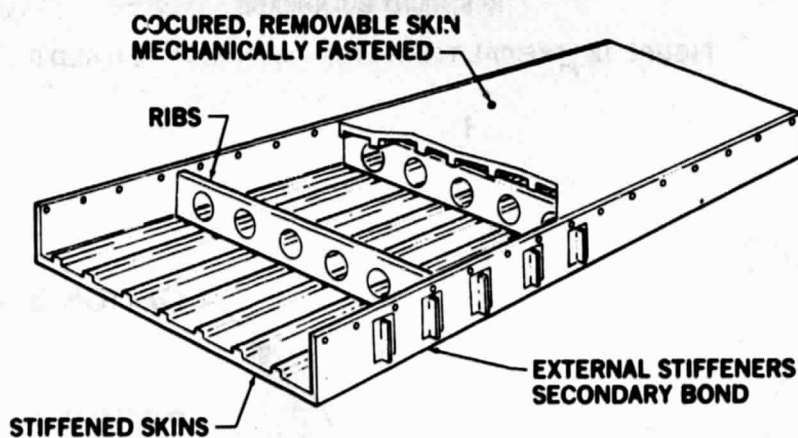


FIG 10-21/64

FIGURE 10. MANUFACTURING TECHNOLOGY – ALL OPTIONS

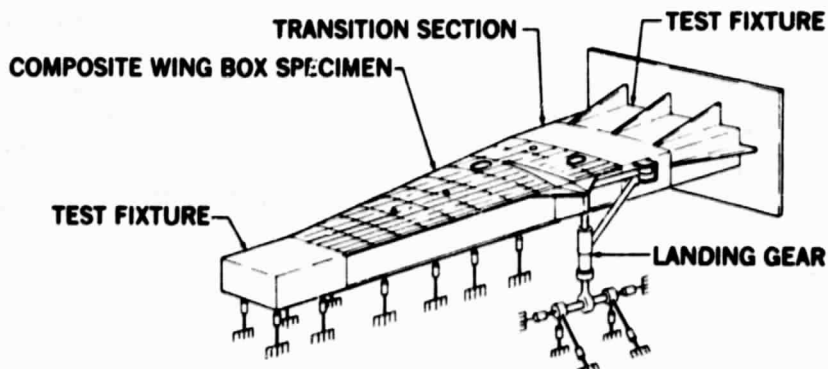


FIGURE 11. WING BOX TEST SETUP – OPTION 1

FIG 11-24/76-1

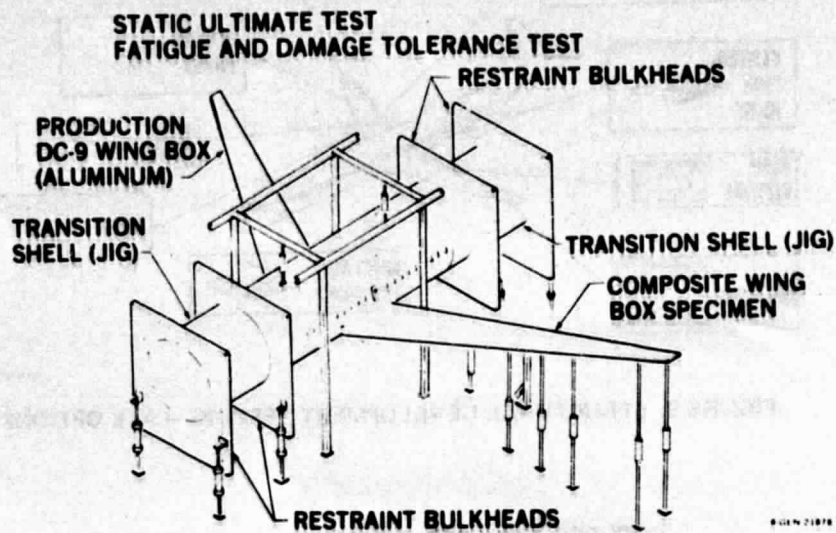
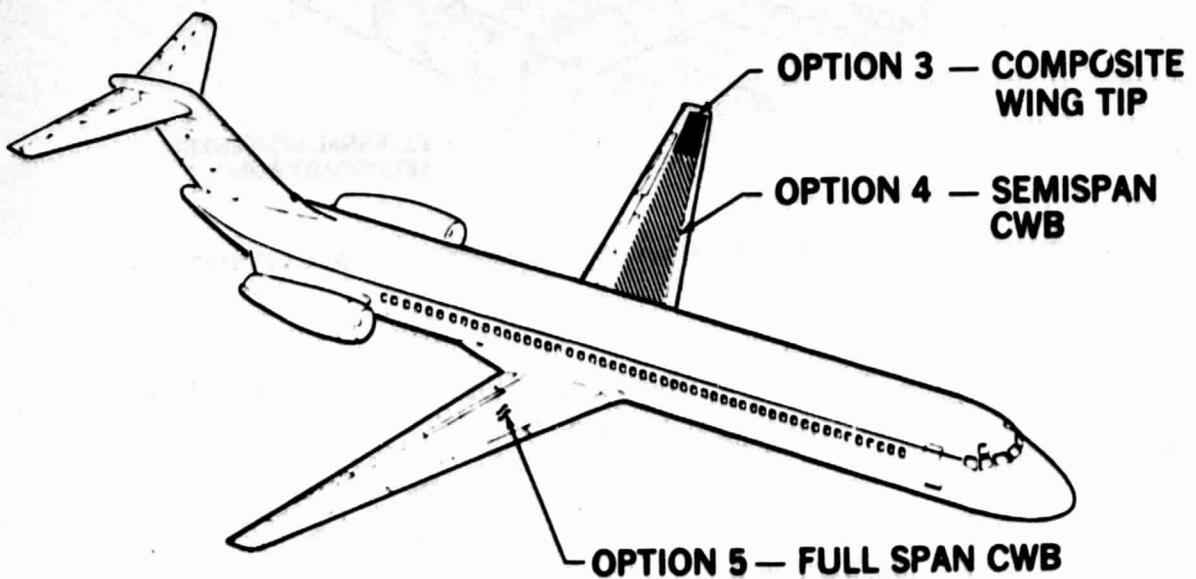


FIGURE 12. TYPICAL TEST SETUP – OPTIONS 2, 3, 4, AND 5

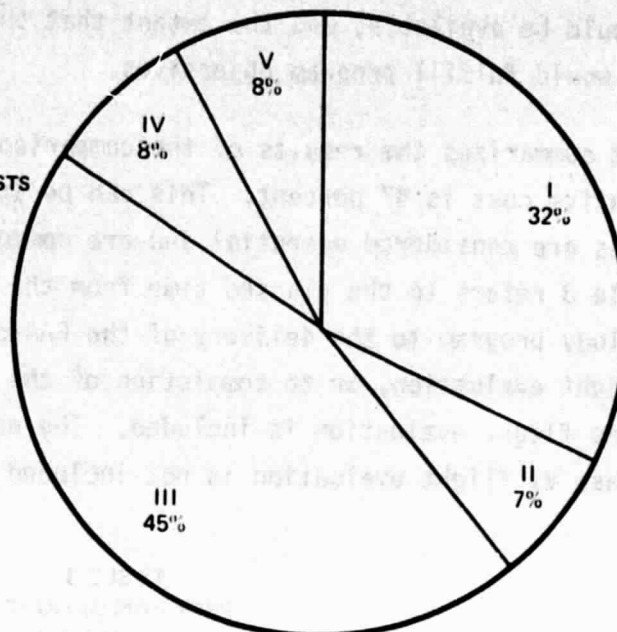


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FIGURE 13. FLIGHT EVALUATION PROGRAM

PHASE

- I DEVELOPMENT
- II DETAIL DESIGN
- III MANUFACTURING
- IV FULL-SCALE VERIFICATION TESTS
- V FLIGHT AND DEVELOPMENT



**FIGURE 14. COMPOSITE WING TECHNOLOGY PROGRAM:
DISTRIBUTION OF FUNDS AMONG PHASES
FOR OPTION 4**

The quality of the technology and data is influenced by how closely the development program is representative of a new aircraft program. Options which do not produce flight hardware can feature structural arrangements and design concepts more ideally suited to composite structures. Options which specify a flight evaluation program are constrained by the need for composite hardware to interface with existing subsystems and adjoining metal structures. Compromises must be made which reduce the cost/weight benefits of the composite wing. These compromises are offset by the touch of realism added to a program which produces flightworthy hardware. Knowing that the final product will eventually be used in revenue service will imbue the same attitudes in the members of the development program team that exist in those associated with a production program. In the same sense, greater confidence in the technology and data produced from a flight program can be expected from the commercial transport aircraft community.

The five program options have been compared to select the option best qualified to form the basis for a contractual technology development effort. The five

options were evaluated in terms of relative cost, the time when technology and data would be available, and the extent that the technology gained from each option would fulfill program objectives.

Table 3 summarizes the results of the comparison. The range of the variation of relative cost is 47 percent. This can be attributed to the fact that many features are considered essential and are common to all options. The schedule in Table 3 refers to the elapsed time from the start of the composite wing technology program to the delivery of the FAA-certified aircraft to an airline for flight evaluation, or to completion of the test program for the option where no flight evaluation is included. The estimated five years to conduct the Phase VI flight evaluation is not included in the table.

TABLE 3
PROGRAM OPTIONS
EVALUATION

OPTION	RELATIVE COST	SCHEDULE (YEARS)	TECHNOLOGY GAIN (PERCENT)
1	0.77	5	70
2	0.93	6	85
3	0.95	6	90
4	1.00	6	100
5	1.13	6	100

Program Option 4 offers the best combination of technology gain versus cost with the same availability of technology and data. Option 4 provides the airline with the opportunity for routine inspection, experience, and maintenance. The expected technology gain is considered adequate to impart the level of confidence required for acceptance. Option 5 does not add a significant gain in technology to justify the 13-percent increase in program costs.

From the comparison of the five options, Option 4 is judged to be the most outstanding and will be used as the basis for the formulation of the development plan.

CONCEPTUAL DESIGN

A conceptual design of a DC-9 composite wing box was developed to replace a metal wing on an aircraft for flight evaluation. It forms the basis for the development plan which outlines the design, manufacturing, and testing efforts required for a prototype flight article. The design layouts emphasize those aspects of the structure that are unique to the composite components and interface with adjoining structure, control surfaces, and aircraft subsystems. The design is also the basis for cost estimates derived for the composite wing box technology development and hardware construction.

Structural Design Criteria and Loads

The criteria used for the conceptual design included the interface requirements, stiffness, strength, and probable manufacturing methods and capabilities. This information permitted the general arrangement and preliminary sizing of structural elements to be defined by layouts, existing analytical methods, and available data.

Interface criteria govern the locations of support structure. All components associated with the interface of the wing box and external systems, such as the main landing gear and flap, must remain where they now are on the metal wing in order to avoid redesign of those systems.

The stiffness criteria require that the same bending and torsional stiffness provided by the metal wing box (Figure 15) be maintained in the composite design. This ensures that the same wing load distribution will be imposed on both the CWB and attaching structure, thereby eliminating the need for a new loads analysis or redesign of attaching structure. It also ensures adequate flutter characteristics.

Strength is always a basic criterion in any design. The CWB components were designed to satisfy the strength requirements of Reference 3.

The conceptual design assumes both advancements in and limitations of manufacturing technology expected in the 1980-1985 period.

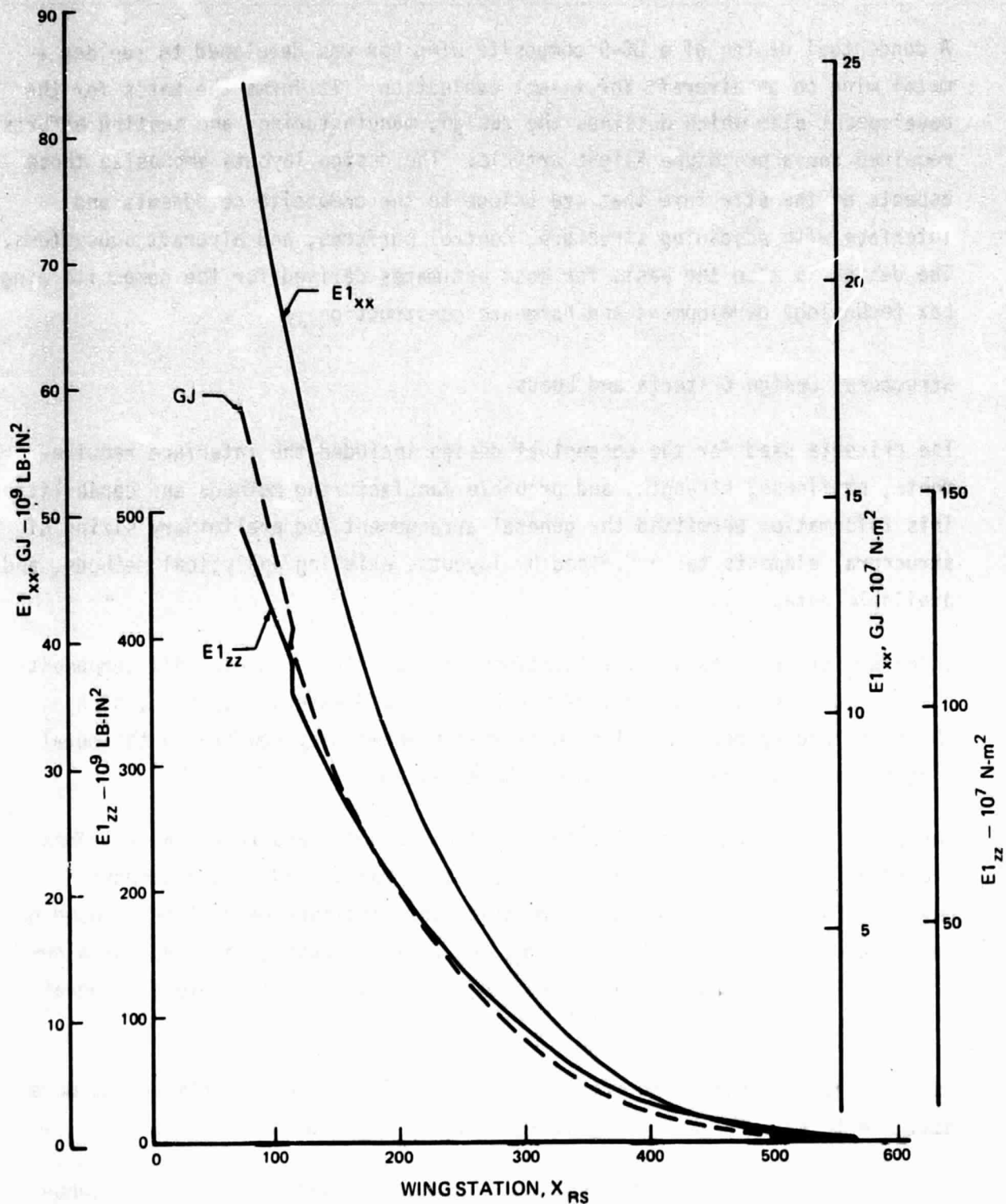


FIGURE 15. DC-9 METAL WING BOX STIFFNESS

The internal loads used in this design effort were the same as for the DC-9 metal wing. These include basic wing bending, shear, torque, and fuel pressure loads which are reduced to internal component loads and support reactions. Skin panel loading (Figure 16) has the major impact on this design and resulting weight estimates.

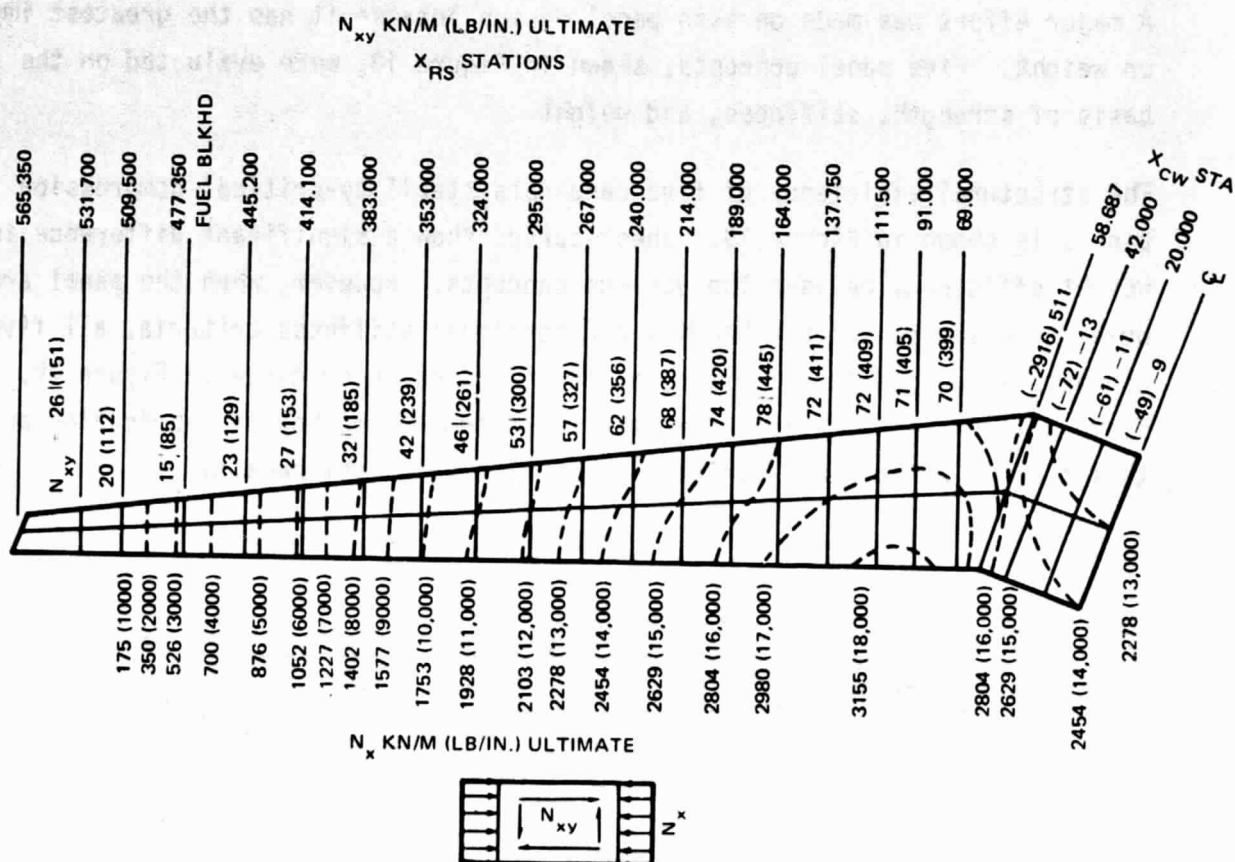


FIGURE 16. SKIN PANEL ULTIMATE LOADS

Concept Selection

The general arrangement selected for the conceptual design is a two-spar, multirib configuration with the spars and ribs in the same location as in the existing metal design, as shown in Figure 17. This selection was primarily based on the interface criteria. The retention of the DC-9-32 configuration minimized changes in multirib arrangement load paths, interface provisions, and fuel tank requirements, and facilitated the development of viable concepts to the extent required to define the development plan.

A major effort was made on skin panel design because it has the greatest impact on weight. Five panel concepts, shown in Figure 18, were evaluated on the basis of strength, stiffness, and weight.

The structural efficiency of five candidate stability-critical compression panels is shown in Figure 19. These curves show a significant difference in weight efficiency between the various concepts. However, when the panel areas were increased to satisfy bending and torsional stiffness criteria, all five concepts were equally efficient, as shown by the upper curve in Figure 19. Blade stiffening was selected as the least complex method of fabrication and thus the one which would minimize costs with no weight penalty.

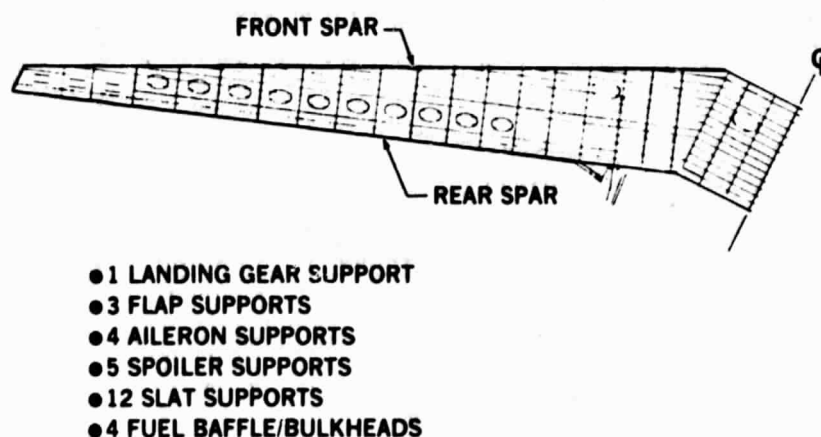


FIGURE 17. STRUCTURAL ARRANGEMENT

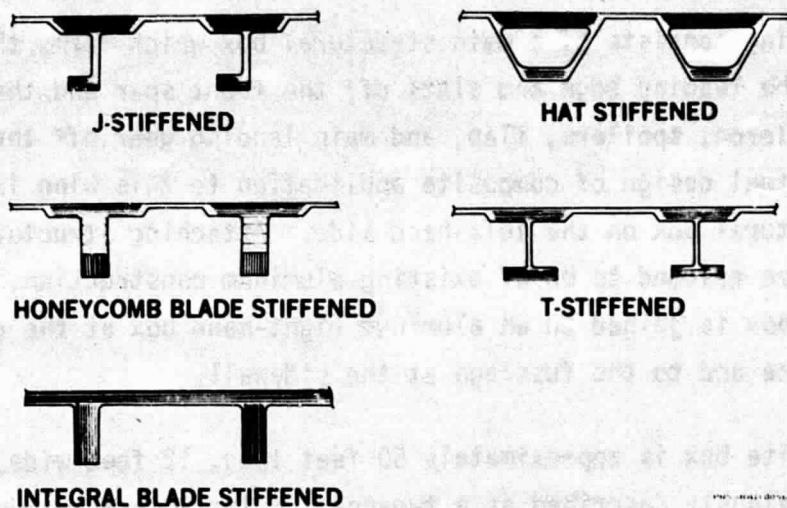


FIGURE 18. COVER PANEL CONFIGURATIONS

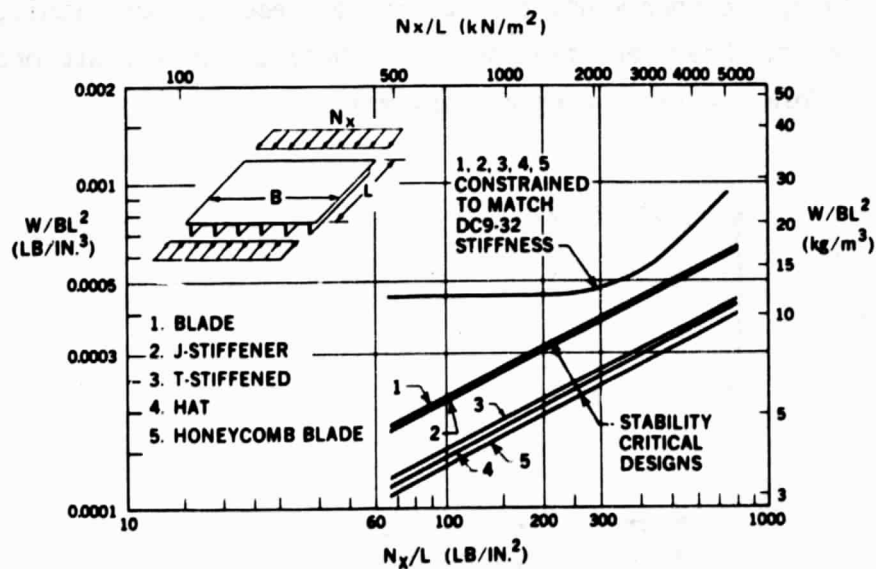


FIGURE 19. STRUCTURAL EFFICIENCY COMPARISONS OF COVER PANEL DESIGNS

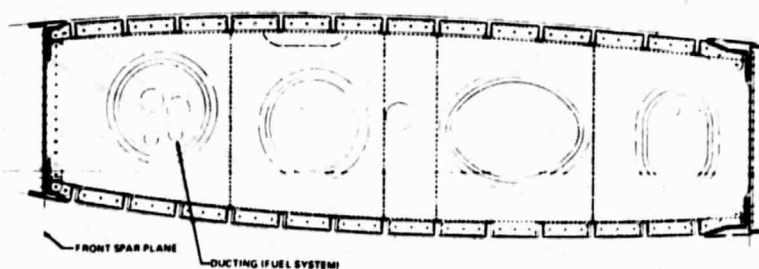
Structural Description

The DC-9 wing consists of a main structural box which forms the fuel tank and supports the leading edge and slats off the front spar and the trailing edge panels, aileron, spoilers, flap, and main landing gear off the rear spar.

The conceptual design of composite application to this wing is limited to the main structural box on the left-hand side. Attaching structure and control surfaces are assumed to be of existing aluminum construction. The composite left-hand box is joined to an aluminum right-hand box at the centerline of the airplane and to the fuselage at the sidewall.

The composite box is approximately 50 feet long, 12 feet wide, and 2 feet deep. It was previously described as a two-spar, multirib arrangement with each sub-component in the same location as its metal counterpart. Each composite member performs the same function and resists the same loads as the aluminum member it replaces.

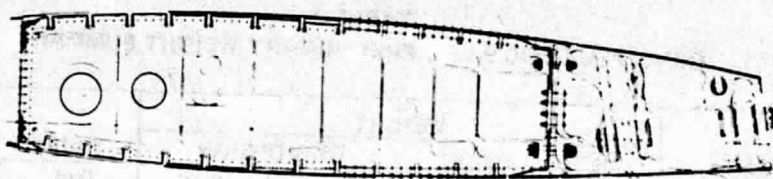
The basic structure is presented in Figure 20. It consists of two monolithic, cocured, blade-stiffened skin panels, which include the spar cap integrally cured in place, two spar webs, and 22 rib webs each of monolithic, cocured blade-stiffened, shear-resistant design. These components are mechanically attached to form the final wing box assembly.



- BLADE-STIFFENED COVER PANELS
- BLADE-STIFFENED, SHEAR-RESISTANT SPAR AND RIB WEBS
- MECHANICAL ATTACHMENTS

FIGURE 20. BASIC STRUCTURAL CONCEPT

A complete CWB design projected for construction in the 1980-1985 period will probably entail the use of some metal for fittings and highly detailed members. The most extensive use of metal in this design is in the main landing gear support area shown in Figure 21. Titanium doublers are cocured into the skin panels to assist the distribution of high, concentrated loads. The level of detail required in the support rib governed the selection of an integrally machined aluminum part mechanically attached to the skin panels and spar webs. The flap and aileron support structure consists of titanium attachment fittings cocured into composite ribs as typified by the aileron bulkhead of Figure 22.



- ALUMINUM BULKHEAD
- TITANIUM DOUBLERS

FIGURE 21. MAIN LANDING GEAR SUPPORT



- COMPOSITE RIB
- TITANIUM FITTING

FIGURE 22. OUTBOARD TANK CLOSURE AND AILERON SUPPORT BULKHEAD

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Weight Estimate

A weight estimate of the conceptual design and a comparison of the design and the existing metal wing box are presented in Table 4.

The effect of design constraints on the composite wing box weight was investigated. Stiffness, two strain limitations, and the conventional strength critical or unconstrained conditions were considered. This investigation was limited to effects of the skin panels as the major contributors to wing weight. For the purpose of this study, rib and spar weights were assumed constant for all design conditions. The results of this study are presented in Figure 23.

TABLE 4
CONCEPTUAL DC-9 CWB PRELIMINARY WEIGHT SUMMARY

COMPONENT	WEIGHT				WEIGHT SAVINGS		
	METAL DESIGN		CWB DESIGN				
	(kg)	(LB)	(kg)	(LB)	(kg)	(LB)	%
SKIN PANELS	2090	4607	1324	2920	765	1687	37
SPAR CAPS	518	1143	384	846	135	297	26
SPAR WEBS	202	445	159	351	43	94	21
RIBS AND BULKHEADS	362	797	266	587	95	210	26
CONTINGENCIES		N/A	156	344	-156	-344	-
TOTAL	3172	6992	2290	5048	882	1944	28

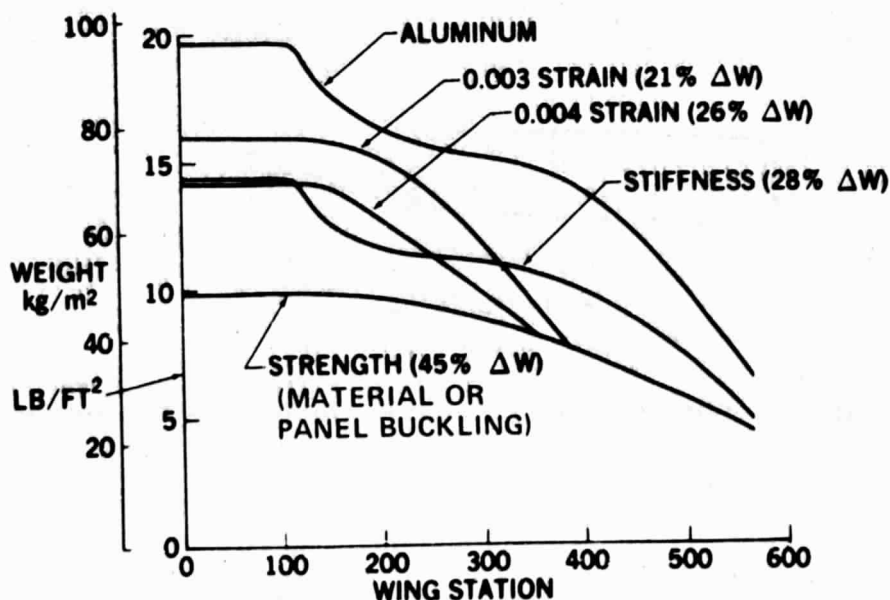


FIGURE 23. DC-9 WING BOX WEIGHT DISTRIBUTION

THE DEVELOPMENT PLAN

A composite wing technology program has been defined which will provide the needed technology and data to support the introduction of primary composite wing structure into production aircraft. The parameters upon which the program was constructed, as discussed earlier, include the acceptance factors, the technology assessment, the selection of a DC-9-32 wing for the basic wing configuration, and the selection of program Option 4 to define the details of the plan.

On this basis, a low-cost program has been established which will meet program objectives with an acceptable risk level and will address the issues considered most critical by the commercial air transport community.

The statement of work for the development plan has been sequentially scheduled in six phases, as shown in Figure 24. Table 5 summarizes the tasks to be accomplished by departmental functions for the six program phases. Cost, schedule, and technical performance can be monitored and evaluated, and program redirection can be effected as downstream developments diverge from predictions. Each phase can be separately funded to allow a reallocation of funds to support the redirection. This will tend to minimize the programmatic risk associated with creative endeavors.

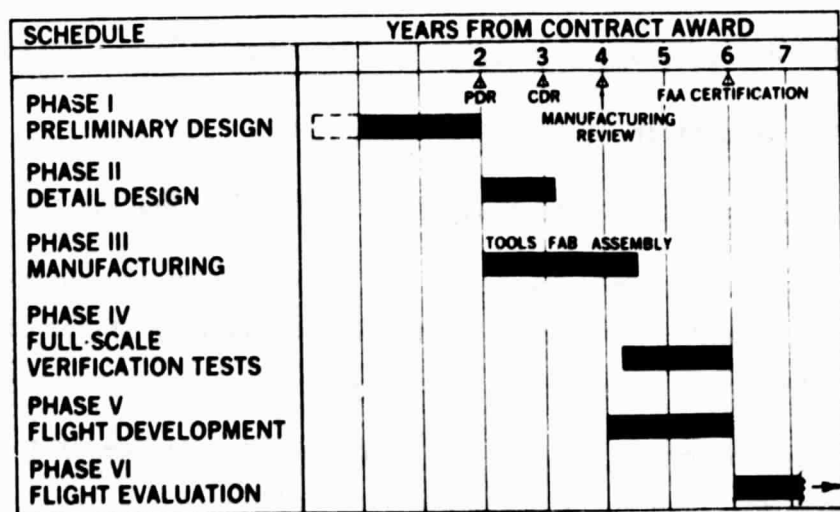


FIGURE 24. DEVELOPMENT PLAN SCHEDULE

**TABLE 5
DEVELOPMENT PLAN**

	ENGINEERING PLAN	MATERIAL AND PROCESSES PLAN	MANUFACTURING PLAN	QUALITY ASSURANCE PLAN	TEST PLAN
PHASE I PRELIMINARY DESIGN	DESIGN SYNTHESIS CONCEPT SELECTION	TECHNOLOGY DEVELOPMENT MATERIALS SELECTION	TECHNOLOGY DEVELOPMENT RISK ASSESSMENT	CONCEPT REVIEW	COMPONENT DEVELOPMENT TEST
PHASE II DETAIL DESIGN	FINAL DESIGN AND ANALYSIS PRODUCTION DRAWINGS	MATERIAL AND PRODUCIBILITY STANDARDS	COMPONENT MANUFACTURING VERIFICATION	SPECIFICATIONS PROCEDURES TRAINING	COMPONENT VERIFICATION TESTS
PHASE III MANUFACTURING	SUPPORT DESIGN CHANGES	SUPPORT	1 FULL SCALE SUBCOMPONENT 3 CWB SEMISPANS	MATERIAL PROCESSES COMPONENTS AND ASSEMBLIES	-
PHASE IV FULL SCALE VERIFICATION TESTS	TEST REQUIREMENTS SUPPORT DATA ANALYSIS	-	-	-	FULL SCALE SUBCOMPONENT AND CWB SEMI- SPAN GROUND TESTS
PHASE V FLIGHT DEVELOPMENT	WING INSTALLATION DESIGN TEST REQUIREMENTS DATA ANALYSIS	-	AIRPLANE MODIFICATION 1 CWB SEMISPAN FABRICATION CWB INSTALLATION	-	AIRPLANE GROUND TESTS AND FLIGHT TESTS
PHASE VI FLIGHT EVALUATION	MONITOR EVALUATION	-	-	-	-

In summary, the development plan contains the following provisions:

- A comprehensive technology development program.
- The design of a DC-9-32 composite wing based on the conceptual design.
- The design and construction of large tools for composite parts.
- The production of flightworthy hardware.
- Test verification to meet FAA structural integrity requirements.
- Installation of a composite wing box on a certified DC-9-32 aircraft with subsequent ground and flight tests to qualify it for commercial revenue service.
- The monitoring and evaluation of the performance of the composite wing box for five years while in revenue service.

The development plan also includes the engineering plan, materials and process plan, manufacturing plan, quality assurance plan, and test plan.

Engineering Plan

The preliminary design will be developed using existing DC-9-32 design loads and criteria. Structural elements will be sized to match the bending and torsional stiffness of the DC-9-32 aluminum wing box. A study has been completed which found that with these stiffness constraints, the easier-to-manufacture blade stiffeners do not impose a weight penalty when compared to more structurally efficient stiffener concepts. To facilitate the interface with aircraft structure and subsystems, the load paths, clearance, and access openings remain much the same. Changes in the existing design will be made as a result of the unique features of composite materials such as fabrication methods, lightning protection, and access for assembly, inspection, maintenance, and repair. The iterative design process is shown in Figure 25.

Layouts of the preliminary design will be prepared to support trade studies, to define the design sufficiently for a preliminary design review, and to provide early information to manufacturing for advance planning and initiation of tool design.

Development tests will be conducted to develop material properties and characteristics and to provide data for the selection, sizing, and detail design of panel and joint structural elements.

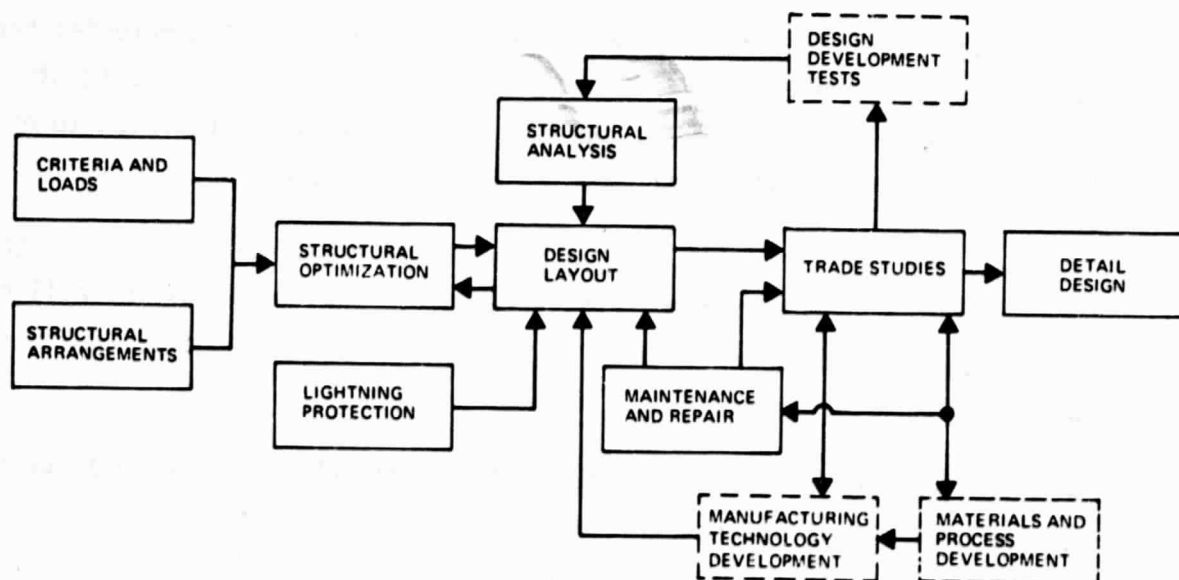


FIGURE 25. DESIGN SYNTHESIS PROCESS

Detail drawings of the composite wing box will be prepared and approved for strength on the basis of compliance with applicable FAA requirements in accordance with Reference 1. Documentation of the analyses and data will be prepared and submitted for FAA approval.

Production readiness, static, fatigue, and damage tolerance verification tests will be conducted to verify the design integrity before production begins and to provide allowable strength data. Engineering will prepare the test plan for Phase IV full-scale testing, monitor the test, evaluate the test results, and document the test results for submittal to the FAA.

Materials and Process Plan

The Materials and Producibility Engineering department will support the design, manufacturing, and quality assurance functions. Procedures will be followed to ensure that all FAA certification requirements can be satisfied per FAA guidelines (Reference 1).

The material systems to be used for a wing structure will be selected at the time of the actual program. The materials considered will have proven handling and processing capability and acceptable mechanical properties. Special emphasis will be placed on long-term environmental properties, impact toughness, and resistance to microbiological fuel contamination.

A material specification will be prepared to identify basic material handling, physical, and composite laminate structural properties. Preimpregnated incoming quality control tests and requirements will be specified to ensure acceptable and reliable structural laminate properties.

A processing specification will be prepared to prescribe a detailed step-by-step manufacturing process for the wing structure. The specification will provide manufacturing tolerances as well as in-process quality control test methods and acceptance criteria.

A nondestructive test Douglas Process Standard will be prepared to prescribe NDT methods and acceptance criteria for the wing structure.

Materials and Producibility Engineering will assist and support the manufacturing development plan for low-cost, reliable manufacturing and tooling concepts.

Manufacturing Plan

The manufacturing plan features early development of manufacturing technology to resolve the choice of the manufacturing method to be utilized for preliminary design of the CWB. The process is one of design synthesis since the manufacturing method affects the design while other design considerations in turn influence the selection of the manufacturing method. As part of the manufacturing development, it is proposed to build six to ten 28-foot box sections, as shown in Figure 10. Three manufacturing approaches and molding concepts will be investigated with these box sections:

1. The more conventional low-risk method utilized for the conceptual design — skins, spars, and ribs individually molded and bolted together.
2. The eggcrate — front and rear spar and ribs are cocured. The stiffened skins are separately cured and attached to the monolithic substructure.
3. A cocured box with the substructure and cover panels as one monolithic part. This concept is the most innovative approach and represents the greatest potential for low-cost manufacture due to the reduction in parts and assembly operations.

Fabrication of the box sections will be carefully monitored to obtain tooling and manufacturing cost, the manufacturing risk areas, and schedule data to provide a basis for economic comparisons and evaluations.

Until the technology development proves that more advanced methods are viable, the development plan calls for full-scale DC-9-32 CWB hardware for laboratory test and flight development to be produced by the conventional methods of mechanically attaching the subcomponent cover panels, spars, ribs and bulkheads which are molded as monolithic parts (see Figure 26).

Typical fabrication details are shown in Figure 27. After densification, the parts will be stored in a freezer until ready for cocuring. Figure 28 shows how the densified wing skins are placed on the plastic laminating mold (Figure 29) with the stringer, intercostals, and mandrels in position. The entire panel will then be bagged and placed in the autoclave as shown in Figure 30. Spars and ribs are treated in a similar fashion.

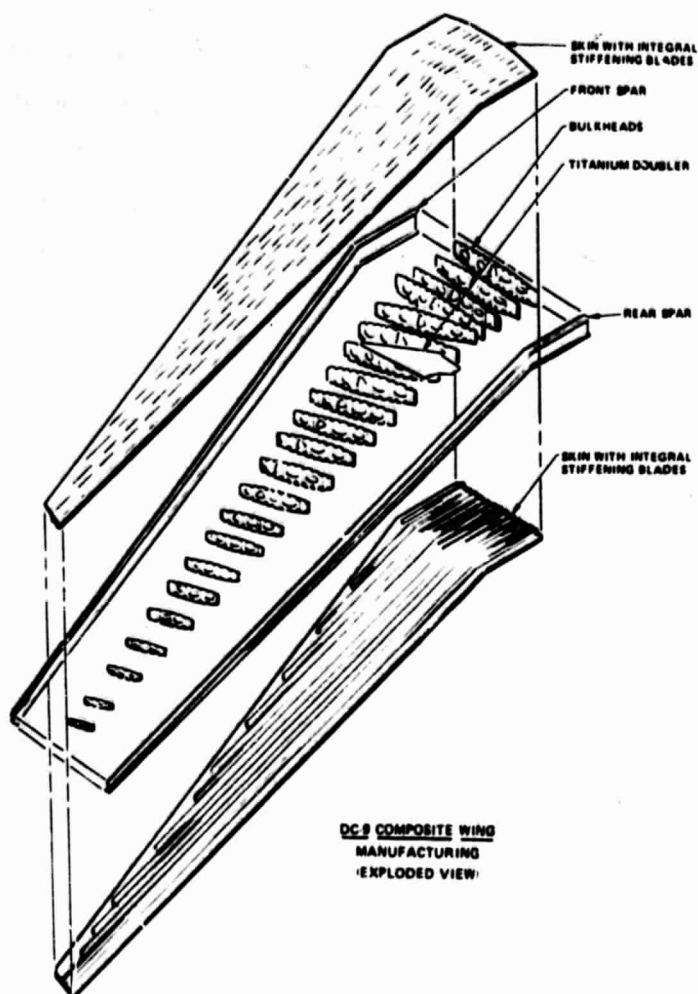


FIGURE 26. DC-9 COMPOSITE WING

	SKIN	BLADE STRINGERS	INTERCOSTAL	RIBS
MATERIAL	BROADGOODS	BROADGOODS PLUS TAPE	BROADGOODS	BROADGOODS
TOOLS	SKIN MOLD 	PERFORM MANDRELS 	BLOCK MANDREL 	MOLD 
FABRICATION	LAYUP METAL INSERTS DENSIFY	45° CHANNELS OF BLADES DENSIFY	LAYUP DENSIFY	LAYUP DENSIFY

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FIGURE 27. FABRICATION DETAILS

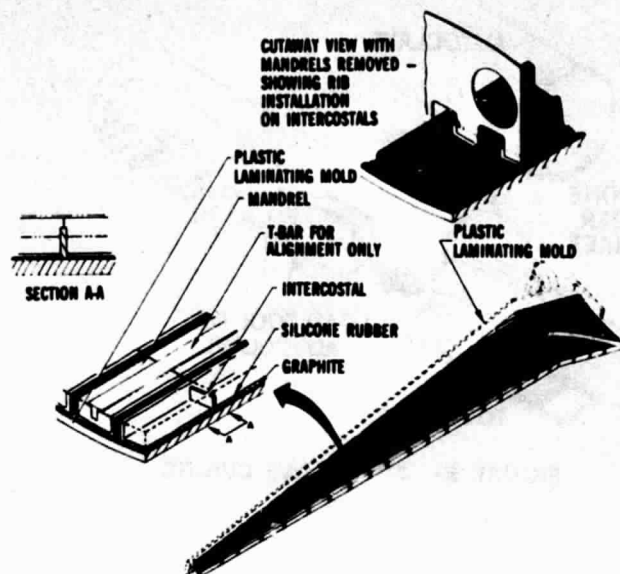


FIGURE 28. SKIN PANELS ON PLASTIC LAMINATING MOLD

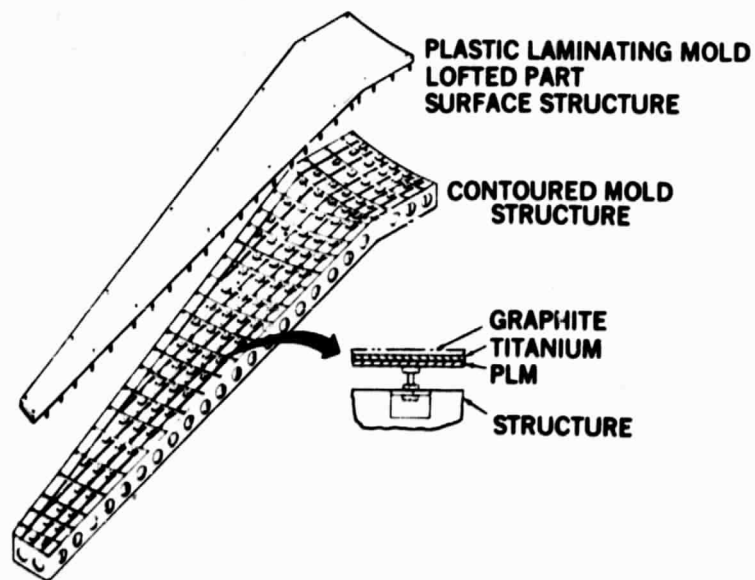


FIGURE 29. PLASTIC LAMINATING MOLD

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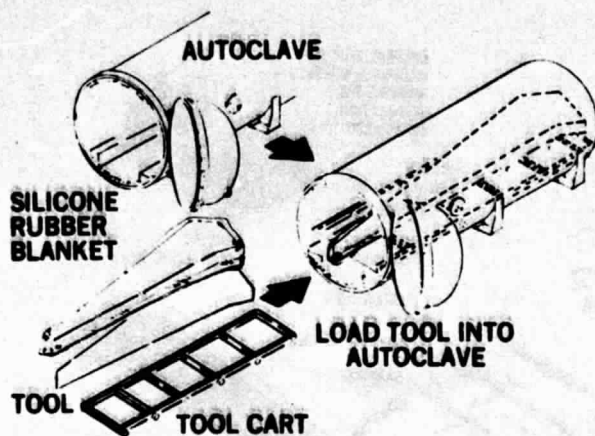


FIGURE 30. AUTOCLAVE CURING

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The cured subcomponents will then be assembled into a structurally complete wing box, as shown in Figure 31.

A DC-9-32 will be modified for the installation of a left-hand composite wing box. Structural interfaces and subsystems will be made compatible with the composite wing box in accordance with engineering instructions, and the airplane will be put in a flightworthy condition for delivery to the test department.

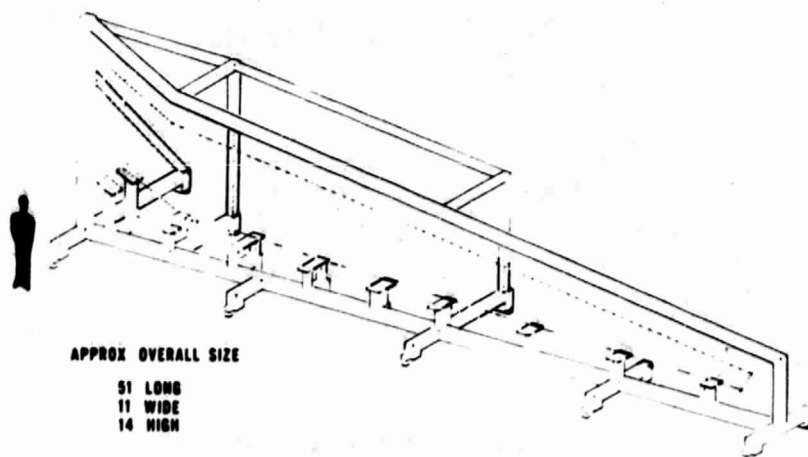


FIGURE 31. FINAL WING ASSEMBLY

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Quality Assurance Plan

Candidate structural concepts will be reviewed in Phase I to determine their compatibility with quality assurance techniques. Concepts which will not permit thorough inspection will be eliminated from further consideration.

The final detail design will be reviewed in Phase II. Particular attention will be given to access provisions to ensure that all areas, internal and external, are accessible for manufacturing and field inspection. NDT specifications will be reviewed and inspection methods developed to ensure the structural integrity of the product. A training program will be conducted to qualify personnel in the use of these methods. The quality assurance systems of appropriate suppliers will be surveyed to ensure proper quality of incoming materials.

Surveillance of the entire manufacturing process will be maintained in Phase III. All incoming materials will undergo inspection and be certified if they comply with applicable Douglas Material Specifications. The various laminating, curing, and assembly processes will be monitored to ensure proper limits and tolerances according to the applicable Douglas Process Standards. NDT methods will be applied to the inspection of all structural components, subassemblies, and final assemblies as prescribed in the Douglas Process Standards. Corrective action will be recommended for material or finished structure which does not meet quality standards. Deviations will be documented and any concessions granted will be authorized by the cognizant engineering staff.

Test Plan

Extensive testing is required to provide a data base for the preliminary design, verify the final design of structural components, and substantiate the integrity of the full-scale composite wing box structure to the FAA regulatory requirements of Reference 3. Coordination must be maintained with the FAA for approval of test plans, test article conformity, test operations, and test results. The certification guidelines recommended by Reference 1 were the basis for definition of the test program.

The test plan is composed of tests in four of the program phases:

- Phase I - development tests
- Phase II - design verification tests
- Phase IV - full-scale verification tests
- Phase V - aircraft ground and flight tests.

The Phase I structural tests selected during the preliminary study include 1346 laminate properties tests and 263 structural component concept development tests, as shown in Figure 32. The tests will develop data for static strength, durability, and damage tolerance over a range of temperature and humidity conditions. Specimen design and test requirements will be designated by Engineering as part of the design synthesis. Test data will be generated for candidate concepts — in the design, damaged, and repaired configurations — for a range of humidity and temperature conditions. A lightning protection test program will be established to investigate fuel tank ignition hazards due to in-tank arcing in the restrike zone, and lightning transient effects on critical electrical wiring components for transient suppression/shielding designs. A static electricity test program will be defined to evaluate the static charge dispersion characteristics of graphite/epoxy composite fuel tank structure.

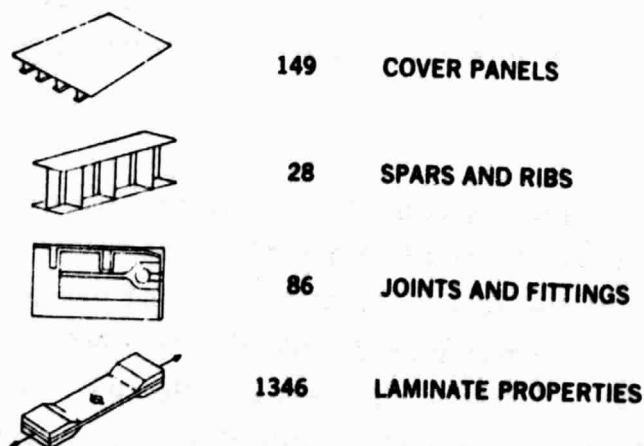


FIGURE 32. DEVELOPMENT TEST SPECIMENS

Production readiness verification tests will be conducted during Phase II on panels, component sections, joints, and fittings to verify that the final design details evolved from the preliminary design satisfy functional and FAA requirements. Thirty tests similar in nature to the development tests are planned with preconditioned specimens at ambient temperature.

Full-scale verification testing will be conducted during Phase IV on three test articles. Test plans will be approved and the tests witnessed by FAA for compliance with FAA regulations. Test results will be submitted to the FAA for approval.

A static test will be conducted on the composite wing box utilizing a production DC-9 right-hand wing box and center fuselage section, as shown in Figure 33. Tests will be conducted to verify the design stiffness, design limit strength, and design ultimate strength for critical DC-9-32 load conditions. After these tests are completed, failure loads will be applied for the most critical condition.

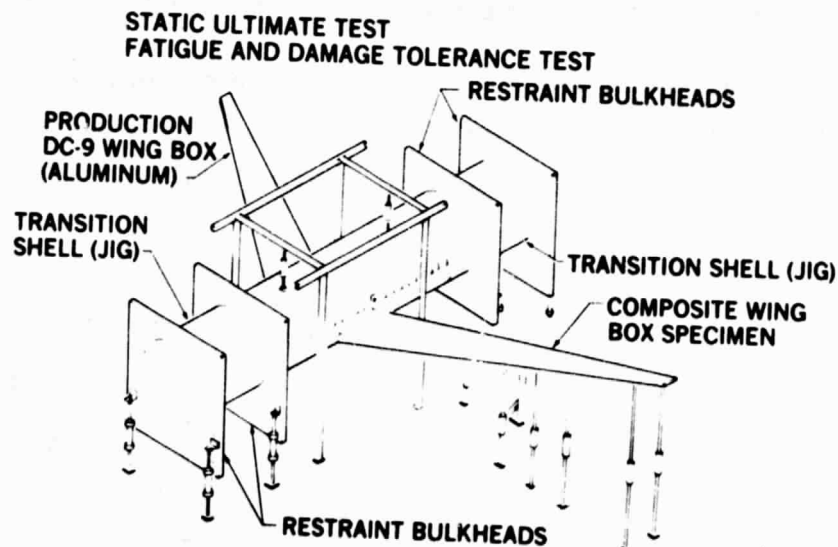


FIGURE 33. CWB SEMISPAN GROUND TEST SETUP

A fatigue and damage tolerance test of the composite wing box will be conducted utilizing the same test setup. DC-9-32 load spectra will be applied for the equivalent of two aircraft service lifetimes (80,000 landings and 72,000 flight hours). Test results are expected to reveal fatigue-critical areas and to provide a basis for service inspection intervals and repair procedures. At the end of the first lifetime, a limit load will be applied to the structure to demonstrate the fail-safe residual strength of the composite wing box.

Damage tolerance tests will be included as part of the fatigue test program. Inherent flaws and deviations formed during manufacture will be monitored during the tests for growth characteristics and will be repaired as necessary to maintain structural integrity. Additional flaws will be induced at the end of the first lifetime and monitored throughout the second. A limit load will then be applied to demonstrate the residual strength of the wing box in the flawed condition. The induced flaws will then be repaired and damage inflicted to represent major damage that might occur in service. The damaged area will then be repaired using the same techniques and equipment with which in-service repairs would be made. Design ultimate loads will be imposed on the repaired area to demonstrate its structural integrity.

The third large test article is the major subcomponent shown in Figure 34 which will be used to verify the crashworthiness characteristics of the main landing gear support structure. A structural overload will be applied to a

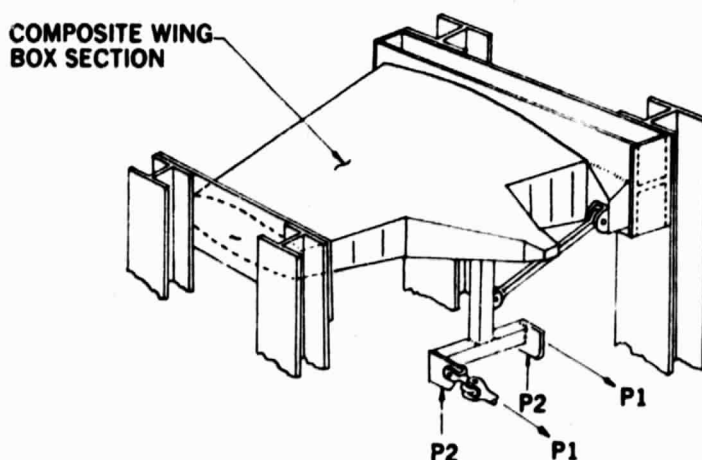


FIGURE 34. FULL-SCALE SUBCOMPONENT/CRASHWORTHINESS TEST SETUP

dummy landing gear to demonstrate that the landing gear will separate from the wing without rupturing the fuel tank in accordance with FAR 25.721. The resulting damage will be repaired by methods expected to be in use at a major repair depot, and the structure will then be tested to ultimate load in order to demonstrate the structural integrity of the repair.

Modal vibration tests are to be conducted on all full-scale semispan composite wing box articles to determine basic vibration characteristics for correlation with DC-9-32 data. These data will also be used to evaluate any stiffness degradation due to fatigue loading.

The third semispan test article will be installed as the left-hand wing on a DC-9-32 airplane. This airplane will undergo ground and flight tests required for FAA certification prior to entering airline service for the flight evaluation phase. Specific aircraft ground tests are required prior to the first flight. These tests include subsystem functional tests, fuel system calibration and gauging, lateral control system proof and operation tests, and aircraft ground vibration tests. Flight test demonstration will be limited to flying qualities, in-flight subsystem tests, and structural and aerodynamic damping tests.

FACILITIES AND EQUIPMENT

Requirements for facilities and equipment have been established for composite primary wing structure:

1. As required for construction of the DC-9-32 composite wing structure defined by the development plan.
2. As required for construction of composite primary wing structure on the production short-haul transport.

Table 6 lists the requirements in a general sense and Figure 35 shows how the floor space would typically be utilized and equipment located. Figure 36 is probably more useful in that it forecasts the facilities buildup based on the road map in Figure 37. The sharp increase in floor space dedicated to composite structure, shown around 1988 in Figure 36, is due to the introduction of the short-haul transport aircraft. The fabrication of hardware for the composite wing technology program would take approximately 4645 square meters (50,000 square feet) of additional floor space beyond the space needed for other composite production programs.

TABLE 6
FACILITIES/EQUIPMENT REQUIREMENTS

	DEVELOPMENT FACILITY	PRODUCTION FACILITY
TOOLS	1 SET	4 SETS
CUTTING EQUIPMENT	WATERJET SYSTEM	2 WATERJET SYSTEMS
NDI	C-SCAN X-RAY	ADDITIONAL C-SCAN X-RAY
AREA	9,290 m ² (100,000 FT ²)	13,935m ² (150,000 FT ²)
MATERIAL STORAGE	2 FREEZERS	4 FREEZERS
CURING EQUIPMENT	2 AUTOCLAVES 2 OVENS	MULTI-SHIFT WORK CYCLE

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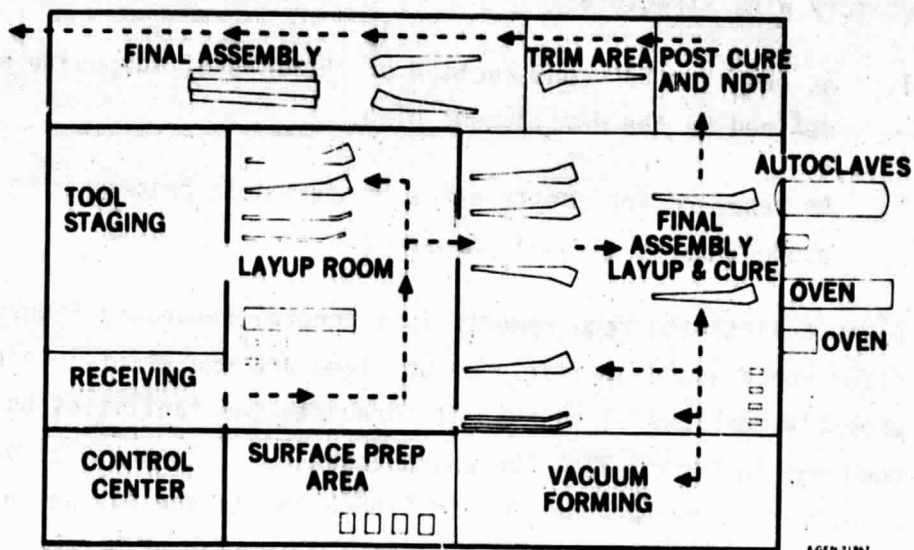


FIGURE 35. COMPOSITE WING DEVELOPMENT FACILITY

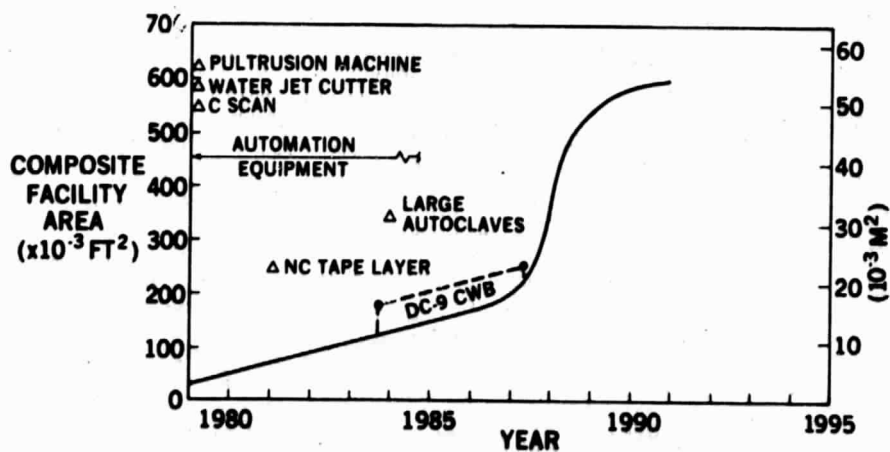


FIGURE 36. FACILITY FORECAST

	DC-10 STRETCH	ADVANCED TECHNOLOGY AIRCRAFT	SHORT HAUL
PROGRAM ATP	1979	1984	1988
1ST DELIVERY	1982	1987	1991
COMPOSITE SECONDARY STRUCTURE	AFT RUDDERS	CONTROL SURFACES NLG DOOR	
	TRAILING EDGE PANELS FAIRINGS LONG DUCT NACELLE		
		FLAPS GEAR DOORS AFT FUSELAGE SECTION	
	FLOOR BEAMS AND STRUTS		
COMPOSITE PRIMARY STRUCTURE		VERTICAL STABILIZER	
			HORIZONTAL STABILIZER WING

FIGURE 37. COMPOSITE APPLICATIONS ROAD MAP

PROGRAM COSTS

The determination of the cost of a composite wing technology program was not specified as a study task. However, rough-order-of-magnitude (ROM) costs were estimated in order to compare program options and to define a minimum-cost development plan without compromising the stated program objectives.

The development plan cost breakdown is presented in Table 7 to provide insight into the scope of the various program tasks.

These cost data were not developed through the rigorous and lengthy bid-work sheet and costing department procedures, and therefore should not be construed as suitable for any other purpose than an approximation of program costs.

TABLE 7
DEVELOPMENT PLAN COST SUMMARY

	APPROXIMATE 1978 DOLLARS (MILLIONS)
PHASE I	
ENGINEERING PRELIMINARY DESIGN	4.0
MANUFACTURING TECHNOLOGY DEVELOPMENT	11.5
DEVELOPMENT TESTING	10.1
PHASE II	
ENGINEERING DETAIL DESIGN	2.5
VERIFICATION TESTS	0.5
MANUFACTURING VERIFICATION	0.5
PHASE III	
TOOLING	29.4
MANUFACTURING (3CWB)	6.3
PHASE IV	
FULL-SCALE VERIFICATION TESTS	4.8
PHASE V	
MANUFACTURING (1 CWB)	2.1
GROUND TESTS	0.4
FLIGHT TESTING	1.0
AIRCRAFT MODIFICATIONS	1.3
ENGINEERING MODIFICATIONS	0.4
	<u>74.8</u>
TRAVEL, COMPUTER, MISCELLANEOUS	0.8
	<u>75.6</u>

APPLICATION AND BENEFITS

The road map presented in Figure 37 reveals McDonnell Douglas Corporation plans for extensive applications of advanced composite materials in future commercial transport aircraft.

The short-haul transport scheduled for introduction in the late 1980s has been selected as the most timely vehicle for composite primary wing structure. As indicated by the road map, extensive applications of secondary and medium primary composite structures will precede the introduction of primary wing structure.

The short-haul transport configuration data include two or four wing-mounted engines depending on the type of engine, an operator's empty weight of 58,060 kg (128,000 pounds), a payload of 16,459 kg (36,285 pounds), 177 single-class passengers, and a range of 6241 kilometers (3370 nautical miles).

Figure 38 depicts the best-estimate schedule relationship between the composite wing technology program and the introduction of the short-haul transport aircraft. In early 1980 to 1984, a management decision must be made in order to market the short-haul transport with a composite wing structure and to develop the advanced design to the level necessary to complete the detail design, fabrication, and assembly within approximately 19 months following a production go-ahead decision. This decision will have to be made on the basis of Phase I technology and data acquisitions, supported by a firm commitment that the other five phases will be carried out.

An analysis was made to determine fuel savings of the short-haul transport with advanced composite structure over conventional aluminum structure in accordance with the road map. The analysis does not include any resizing of the aircraft or engine changes to account for the reduced structural weight. The results of the analysis are shown in Table 8. The total weight saving estimate of 4445 kg (9800 pounds) was derived from in-house experience with secondary structure, proven results from the NASA ACEE DC-10 composite rudder program, preliminary findings from the NASA ACEE DC-10 composite vertical stabilizer program, and the 28-percent weight saving reported herein for composite wing structure.

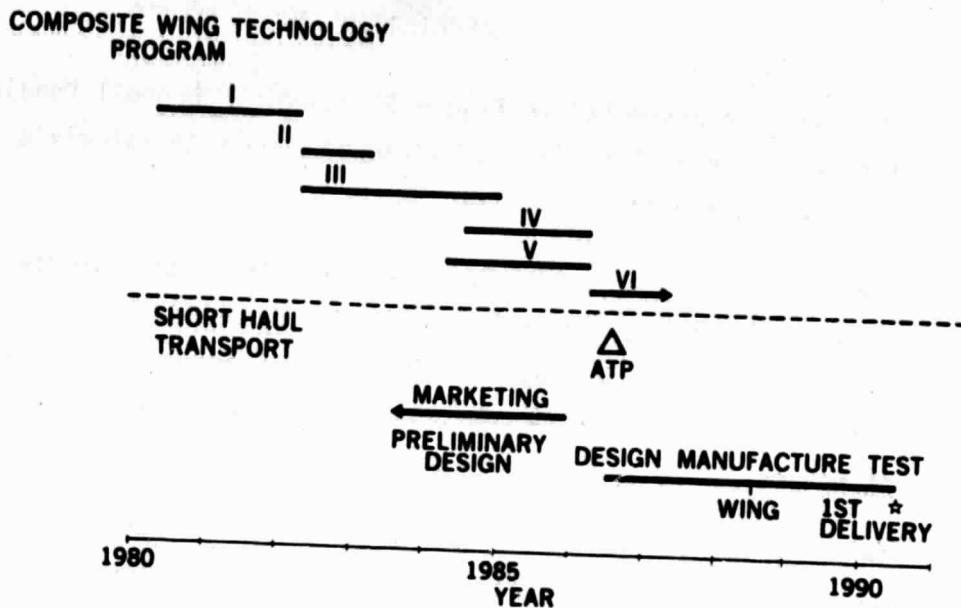


FIGURE 38. TIMELINES OF COMPOSITE APPLICATIONS TO SHORT-HAUL TRANSPORT

TABLE 8

COMPOSITE BENEFITS TO SHORT-HAUL TRANSPORT

WEIGHT SAVINGS – 4,445 kg (9,800 LB)

FUEL SAVINGS – 7,690,000 LITERS (2,000,000 GALLONS)

COST SAVINGS (BASED ON 20-YEAR LIFE)

- 1977 FUEL COST – \$769,000

- PROJECTED AVERAGE COST – \$2,600,000

OR

PAYLOAD INCREASE OF 4,445 kg (9,800 LB)

STUDY CONCLUSIONS

The study results support the conclusion that a composite wing technology program must be undertaken by the commercial transport manufacturer to accomplish the transition from materials and practices utilized in current construction to extensive use of composites in wings of aircraft that will enter service around 1990. Data have been developed to define such a program.

The list of acceptance factors compiled for the manufacturer, FAA, and airlines provides a rational basis for an assessment of composite wing technology.

The assessment indicates the need for a composite wing technology program which contains the following provisions:

1. Development of technology and data to resolve the eight key issues defined herein.
2. Design, manufacture, and test of flightworthy, certifiable, full-scale hardware encompassing a range of wing design features representative of commercial transport aircraft.
3. Demonstration of composite wing technology to the extent that technical, economic, operational, and programmatic risks are reduced to an acceptable level.
4. In-service flight evaluation to provide realism to other phases of the program, and to demonstrate the operational performance of primary composite wing structure.

The conceptual design indicates that the goal of a 25- to 30-percent weight saving is attainable for primary composite wing structure compared to conventional aluminum structure, subject to further limitations which may be imposed as the eight key issues described herein are resolved.

A facilities and equipment plan should be prepared with the realization that the production utilization of composite primary wing structure will be preceded by the extensive utilization of composite secondary and medium primary structure.

The utilization of composite primary wing structure in the 20th century on commercial transport aircraft is dependent on the continued NASA sponsorship of a composite wing technology program.

STUDY RECOMMENDATIONS

1. A NASA-funded composite wing technology program is recommended to exploit the potential of using advanced composite materials for aircraft wings to provide a 25-percent weight saving with a promise of reduced costs throughout the life of the aircraft. These advantages can be realized as experience and technology accrue and mass production reduces material and manufacturing costs.
2. Critical path technology programs should be funded as soon as possible if the 1985-1990 goal for the introduction of primary composite wing structure on new aircraft is to be realized. The key issues which should be addressed first to supply data and technology in a timely fashion are:
 - A. Repair of major damage
 - B. Impact damage (included in durability issue)
 - C. Damage tolerance design studies and tests
 - D. Innovative molding methods
 - E. Tooling methods for large composite structures
 - F. Lightning protection.
3. The remainder of the durability key issues and the two other key issues of crashworthiness and NDI method can be started later in Phase I since sufficient basic data for these technologies are available to support early preliminary design tasks.
4. The NASA Fiscal 1979 budget should include funding to initiate contracted technology development programs with more than one airframe for application to manufacturer composite wing structure.

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